



Original Research Paper

Social Behavioural Changes and Stress Responses in Primates Under Habitat Disturbance and Forest Fragmentation

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Abstract

Some of the most significant anthropogenic threats to primates include habitat disturbance and fragmentation. Primates are cognitively complex, highly social mammals that are often forest dependent and are very sensitive to changes in habitat size, habitat quality, habitat connectivity, food availability, predation risk, and human contact. This review focuses on the effects of habitat disturbance and fragmentation on primate social behavior and stress response, including effects on the social organization, mating behavior, aggression, competition, glucocorticoid activity, self-directed behaviors, and long-term health effects. The experience of primate ecology and conservation biology suggests that habitat loss can lead to a decrease in food availability, an increase in inter- and intra-group competition, alteration of ranging behavior and dispersal patterns, and raise the risk of human-wildlife conflict. Physiologically, disturbed environments are frequently linked to activation of the hypothalamic-pituitary-adrenal axis - the hormone cortisol or the hormone metabolites in feces are often used as markers for this. Exposure to disturbance for a prolonged period can lead to allostatic load, immune dysfunction, reproductive dysfunction, and population declines. Responses, however, are different among taxa, ecological flexibility, food resources, home range size, social system, and permeability of the matrix. While highly frugivorous species with large home ranges may be more likely to be vulnerable, some generalist species can sustain themselves in a fragmented landscape by altering their diet, activity budgets, and ranging. Such conservation efforts must, as a result, adopt a multi-dimensional approach that includes behavioral monitoring, physiological indicators, habitat restoration, ecological corridors, community involvement, and conflict reduction. Conservation planning for primates in a human-dominated environment can be enhanced by knowledge of the relationship between social behavior and stress physiology.

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Introduction

Habitat disturbance is the alteration, degradation, or destruction of natural habitat caused by either anthropogenic or natural processes (Ramsay et al., 2023; Rajan & Chawla, 2024; Kumari & Hussain, 2024). The most important disturbances in primate conservation are deforestation, logging, agricultural expansion, mining, road construction, urbanization, hunting, fire, and pressure from tourists (Shanee et al., 2023). Forest fragmentation is the breaking up of a continuous woodland into smaller and more separated patches of forest, typically within a human landscape (such as farms, roads, plantations, settlements, and degraded vegetation). Fragmentation affects the amount of habitat, spatial configuration, edge effects, ecological connectivity, food distribution, exposure to predators, and access to sleeping and breeding sites (Kaisin et al., 2025; Zhang et al., 2023; Franchini et al., 2023). The usefulness of primates as indicators of environmental changes is due to their dependency on structurally complex forests, long life history, low reproductive rates, specialized diets, and complex social systems (Sadegh, 2016; Hending et al., 2024). Worldwide, primates have been identified as having a high level of threatened species, and habitat loss has been identified as a key driver of primate decline, including that resulting from agriculture, logging, infrastructure, and extractive industries (He & Li, 2024). Human-primate conflict is also likely to escalate when forests are destroyed and replaced by farm plots or villages because primates may

venture into a crop field or village to look for food (Martinez de Zorzi et al., 2024). Population decline is not just due to death or habitat loss, so the study of social behavior, change, and stress responses is essential (Cárdenas-Navarrete et al., 2026; Ramya & Geetha, 2025; Geetha & Babylatha, 2025). Primates can undergo subtle, yet biologically significant shifts in group structure, hierarchy, breeding and other reproductive activity, ranging, feeding time, aggression, and physiological stress before going extinct locally. All of these changes can lead to lowered reproductive success, lower immunity, susceptibility to disease, impaired dispersal, and lower long-term population viability.

Key Contributions:

- Identifies and explains the concepts of habitat disturbance and fragmentation as they relate to primate habitats.
- Describes the effect of habitat alteration on primates' social life and stress reactions.
- Connects behavioral changes (including aggression, group instability, and altered reproduction) to conservation problems.
- Identifies signs of stress (cortisol shifts and self-directed behaviors).
- Highlights the importance of habitat protection, restoration, and community-based conservation.

The first section provides an introduction to the concepts of habitat disturbance and forest fragmentation, as well as the significance of these phenomena in the context of primate conservation. Social behavioral changes such as changes in group dynamics, mating behavior, aggression, and resource competition are

discussed in Section II. Section III provides an explanation of stress responses in primates, particularly physiological changes, including cortisol levels, and behavioral indicators of stress. Major contributing factors such as habitat loss, human–wildlife conflict, and disturbed foraging or movement behavior are highlighted in Section IV. The conservation implications and potential mitigation measures, including conflict reduction, community engagement, and habitat restoration, are discussed in Section V. The paper is concluded with a summary of the main findings in Section VI and some future research and conservation needs in the highlights.

Social Behavioural Changes in Primates

Food distribution, predation pressure, kinship, dominance relationships, dispersal pattern, reproductive strategies, and habitat structure all influence the structure of primate societies. These ecological foundations can shift quickly when forests are broken up. Smaller fragments will accommodate fewer resources, and may force individuals to the smaller area, thus raising population density and contact rates. The review of primate fragmentation indicates that small habitat fragments can lead to decreased food availability, heightened competition, increased physiological stress, and increased extinction risk, both demographically and environmentally.

The size of the group may swell temporarily if the individuals are concentrated into the remaining forest patches, but the crowding could exacerbate the competition and affect the

dominance hierarchy. At other times, groups might divide, as a fragment may not be able to sustain the energy requirements of everyone. Fragmentation can also limit dispersal, especially if the surrounding matrix is hazardous or inhospitable. Dispersal may be reduced and lead to higher inbreeding risk, reduced mate choice, and no rescue effects between subpopulations.

There are significant differences in species' adaptability. Generalist and folivorous primates might be able to survive in smaller fragments by changing their diet and traveling less, but highly frugivorous primates with a large home range are more likely to be impacted. For instance, the habitat fragmentation literature classifies spider monkeys as especially sensitive species, given their reliance on fruit and their large home ranges, whereas howler monkeys are viewed as being more tolerant, because they are able to forage on multiple species of leaves, have relatively small home ranges, and are also active in an energy-conserving manner.

Group size, sex ratios, dispersal possibilities, and availability of unrelated mates may all be affected by fragmentation and thus be involved in mating systems. In isolated forest patches, males or females may not be able to migrate safely from one forest patch to another. This can lead to lower gene flow and higher inbreeding. Roads, farms, plantations, and settlements may be ecological barriers for species where normally one sex disperses to avoid inbreeding.

Nutritional stress can also lead to reduced reproductive success. Changes in the number of fruits available, changes in forest structure, and competition for feeding trees may impact female

body condition, ovarian cycling, successful pregnancy, calf survival, lactation, and feeding tree success. Thus, chronic disturbance can also have indirect effects on reproduction by causing energy limitation, as well as direct effects by causing stress physiology. In primates, cortisol is one of the important glucocorticoids involved in the hypothalamic–pituitary–adrenal axis activation; it is common to use cortisol as a measure of stress in blood, saliva, urine, feces, or hair.

Habitat compression is one of the most obvious behavioral effects – competition. Primates may become more aggressive within and between groups if the food trees, sleeping places, water sources, or safe travel routes deteriorate. Displacement at feeding sites, chasing and biting, vocal threats, coalition attacks, and heightened vigilance are all forms of aggression. When small groups are in separate areas, they will likely have to share resources and so have more intergroup encounters.

There is no equal competition. Alarming, low rank animals, juveniles, lactating females, and dispersing animals may be disproportionately affected due to their less access to food and safer places. These can be individuals who need to spend longer eating poor quality food, go further to obtain resources, or be more at risk from harassment by dominant individuals. This behavior-driven pressure over time could cause a decline in the survival and reproduction rate.

Stress Responses in Primates

Physiological Responses: Cortisol and Glucocorticoids

Stress is a physiological/behavioral reaction to stimuli that interfere with homeostasis. One of the main biological pathways that play a key role in stress is the hypothalamic–pituitary–adrenal axis in primates. This axis is activated when it is needed, and results in the release of glucocorticoids, such as cortisol, which increases energy availability and aids in short-term survival. Repeated or chronic activation can, however, be expensive. In nonhuman primates, cortisol is the primary glucocorticoid product of the HPA axis, and can be measured in blood, saliva, urine, feces, and hair, according to Novak et al.

In disturbed habitats, glucocorticoid levels can be elevated in the absence of food, when present in human habitats, during hunting, logging, heightened aggression, predation risk, heat exposure, and when traveling in an open matrix. But it is important to be aware of some cautions when interpreting glucocorticoids. If cortisol is elevated, the individual is in acute stress; however, chronically stressed persons might have a blunted cortisol response either as a result of physiological dysregulation or as a result of allostatic adjustment. Novak et al. highlight the need to consider chronic stress as a mechanism capable of altering baseline functioning and the fact that abnormal behavior is not necessarily merely an increase in cortisol.

Behavioral Responses: Self-Directed and Coping Behaviors

Stress is also manifested in behavior. Disturbed primates might engage in self-directed activity like scratching, self-grooming, body shaking, yawning, stereotypic movement, vigilance, or social withdrawal between members of their group. These behaviors may be helpful non-invasive markers of anxiety or social stress, particularly in conjunction with hormonal information.

Behavioral coping responses can involve an increase in grooming, coalition formation, avoidance of aggressive individuals, a change in the selection of sleeping sites, a change in preference for crop foods, a reduction in travel, or a change from fruit to leaves and fallback foods. There are short-term adaptive responses, and there are long-term responses that are more costly. For instance, feeding crops may help provide calories but lead to conflict with dogs, vehicles, humans, or electrocution. Likewise, a decrease in travel can save energy but can restrict food diversity.

Effects Of Chronic Stress on Health and Well-Being

The effects of chronic stress on primate health include immune suppression, reproductive inhibition, impaired wound healing, changes in metabolism, parasitic infection, and increased disease transmission. Little areas of high parasite density could result from fragmented habitats where the high-density groups repeat areas of use. Fragmentation reviews highlight that high population densities in fragments can lead to greater competition and parasite pressures, which can lead to longer-term fragility and physiological stress.

It has a big welfare impact. In disturbed habitats, free-ranging primates can experience the following: food shortage, limited mobility, increased aggression, increased human contact, increased disease risk, and decreased reproductive opportunity. These stressors can compound and create a greater impact than if they occurred individually.

Table 1: Stress and Behavioral Responses of Primates Under Fragmented Habitats

Disturbance Factor	Behavioral Response	Stress Indicator	Conservation Concern
Reduced forest cover	Increased ranging and food searching	Higher cortisol level	Energy loss and poor survival
Food scarcity	Aggression and feeding competition	Frequent vigilance	Group instability
Human settlement nearby	Crop foraging and avoidance behavior	Self-scratching and anxiety signs	Human–primate conflict
Loss of corridors	Restricted dispersal	Social withdrawal	Reduced gene flow
Small habitat patches	Increased group crowding	Chronic stress symptoms	Lower reproduction and health

Table 1 outlines the key disturbance factors that impact primates in fragmented forest habitats. The loss of forest cover, scarcity of food resources, human settlement, destruction of forest corridors, and small forest patches may change typical social behavior and lead to a higher level of physiological stress. These answers can lead to lower reproduction rates, weaker group cohesion, more human-wildlife conflict, and jeopardize long-term group survival.

Factors Contributing to Behavioral Change and Stress

Loss of Habitat and Resources

Habitat loss is the short-term driving force. Smaller fragments have fewer feeding trees, fewer places to sleep, fewer ways to escape, and fewer ways to disperse. Fragment size is related to primate persistence, but data suggest that food limitation and population over-density in small fragments can increase competition and stress.

Habitat quality is as important as habitat quantity. A large, but poorly managed forest can offer less fruit, less canopy continuity, or more human impact than a smaller, well-managed forest. Primate behavior and stress can be affected by tree basal area, canopy structure, fruiting phenology, and plant diversity.

Increased Human–Wildlife Conflict

Primates are now more likely to come into contact with farms, roads, settlements, plantations, and domestic animals as forests are reduced. Retaliation, trapping, poisoning, dog attacks, or translocation can occur from crop

feeding. Human activities may also influence primate walking, feeding time, level of vigilance, and social spacing. Human–primate contact is of particular concern since it constitutes a risk for zoonotic and anthroponotic disease transmission.

Conflict is a sign of ecological compression and is not necessarily "problem animal" behavior. Primates may be raiding crops in reaction to a decrease in the number of wild foods or a disruption of movement corridors. Conservation programs need, therefore, to account for the human livelihood needs and the ecological needs of primates.

Disruption of Migration, Dispersal, and Foraging

Unlike birds and ungulates, many primates have not been described as migrating, but instead they utilize seasonal ranging, dispersing, and shifting their foraging over an extensive range. These processes are disturbed when there is fragmentation. Seasonal food patches or opportunities to mate can be blocked by roads, farms, rivers changed by development, or open fields. When patches are widely dispersed, patch isolation can be more detrimental than the loss of any single feeding tree for wide-ranging species.

The quality of the matrix is thus essential. Live fences, secondary vegetation, riparian strips, isolated trees, and shade-grown crops can create improved connectivity and additional resources in landscapes. Fragmentation research points to the fact that landscape connectivity and matrix elements can aid in the movement and resource access of some primates.

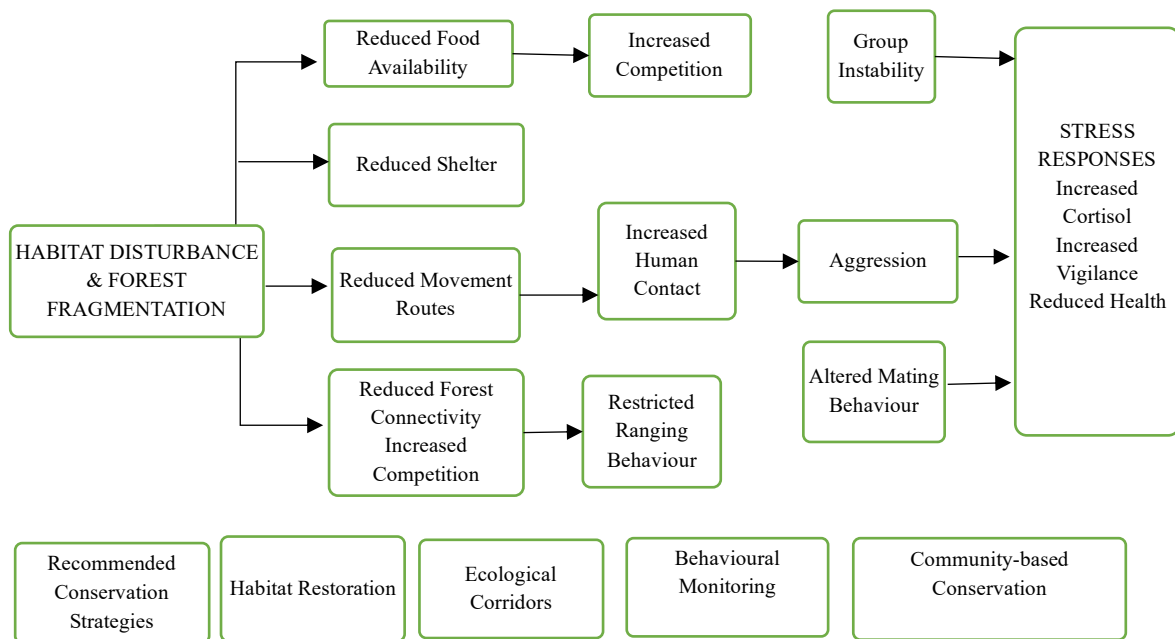


Figure 1: Ecological and Behavioral Pathway of Habitat Disturbance Effects on Primate Populations

Figure 1 shows how habitat disturbance and forest fragmentation can lead to a cascade of ecological and behavioral change in the population of primates. Competition, contact, and limited ranging behavior can be higher when food availability, habitats, and moving routes are reduced, and the connectivity of the forests is reduced. These stressors cause the group to become unstable, aggressive, and changes in mating behavior, as well as stress responses such as elevated cortisol levels, increased vigilance, and poor health. It also underscores some of the critical conservation measures such as 'behavioral monitoring', 'community-based conservation', habitat restoration, and 'ecological corridors'.

Conservation Implications

Knowledge of social behavioral changes and stress response of primates is crucial to formulating effective conservation policies in

disturbed and fragmented forest settings. These are all signs that the habitat is not ecologically supporting primates when they show more aggression, unstable group formation, lowered reproductive success, changed foraging behavior, or increased stress levels. So, conservation planning should not be based solely on the number of individuals, but should include behavioral stability, social health, and physiological well-being (Nautiyal et al., 2024).

The most critical actions to minimize the impacts of forest fragmentation are habitat protection and restoration (Deepika, 2025). To enable primates to travel safely, gain access to food resources, and maintain natural social interactions, native vegetation restoration, forest corridors, protecting feeding and sleeping sites, and enhancing the connectivity between isolated forest patches can be done. All these actions can limit competition, help to bring down stress, and contribute to the survival of the population.

Community involvement is also vital as many of these areas with fragments are adjacent to agricultural fields and human settlements. Human–primate conflict can be minimized through awareness programs, crop protection techniques, non-lethal conflict management, and local participation in habitat restoration. Ecological restoration, community involvement, behavioral monitoring, and stress assessment can be integrated into conservation efforts to enhance protection for primates in disturbed habitats effectively.

Conclusion

Primates are impacted by habitat disturbance and fragmentation in complex ways, both ecological, behavioral, physiological, and social. Habitat loss and degradation can exacerbate competition, group structure, hinder dispersal, decrease reproductive success, and increase human–primate conflict. These pressures can trigger stress responses (usually in the form of cortisol or other glucocorticoids) and can result in chronic allostatic costs if the disturbance continues. Aggression, changes in grooming, self-directed behaviors, crop foraging, and changes in ranging can be early indicators of population stress. There is variation in response from species to species. Large-bodied, frugivorous, and wide-ranging primates may be more vulnerable to being lost from fragments due to their inability to change their diet or activity. Species with large bodies, frugivorous diets, and wide-ranging foraging habits may be more vulnerable to being lost from fragments due to their inability to change their foraging habits or diet. Conservation planning should therefore

transcend the value of forest area and encompass habitat quality, habitat connectivity, social stability, stress physiology, community coexistence, and more. In the future, long-term behavioral observation, non-invasive analysis of hormones, remote sensing, genetic monitoring, disease surveillance, and participatory conservation should be combined in future research. Conservation of primates is to conserve the forest, as well as the social and physiological structure enabling the primate population to reproduce, adapt, and survive. The call to action is urgent: conserving primates in fragmented landscapes must involve coordinated habitat protection and restoration, as well as conflict reduction and evidence-based management that takes into account primates' social complexity and their strong connection to their habitat.

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